

Post-Exercise Oxygen Consumption Following Low-Intensity Resistance Exercise with Blood Flow Restriction Compared to Traditional High- Intensity Resistance Exercise

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TABLE OF CONTENTS

LIST OF TABLES AND FIGURES	3
Part I	4
INTRODUCTION	4
METHODS.....	5
<i>Research Design</i>	5
<i>Participants</i>	5
<i>Study Visits</i>	6
<i>Initial Visit</i>	6
<i>Anthropometric Testing</i>	7
<i>3RM Squat Testing</i>	7
<i>Testing Sessions</i>	8
<i>Traditional Squats</i>	8
<i>Low-Intensity Squats with Blood Flow Restriction</i>	8
<i>Metabolic Data</i>	9
<i>Statistics</i>	10
RESULTS.....	10
<i>Participants</i>	10
<i>Anthropometrics</i>	11
<i>Metabolic Data</i>	12
<i>Respiratory Exchange Ratio and Substrate Utilization</i>	16
DISCUSSION	18
SUMMARY AND CONCLUSION	20
 PART II	 22
Literature Review	22
<i>Blood Flow Restriction (BFR)</i>	22
<i>Acute Blood Flow Restriction</i>	22
<i>Acute Blood Flow Restriction with Treadmill Walking</i>	25
<i>Acute Blood Flow Restriction with Resistance Training</i>	26
<i>Practical Blood Flow Restriction (pBFR)</i>	29
<i>Excess Post Exercise Oxygen Consumption (EPOC)</i>	31
 References	 36

Appendix A: Informed Consent	39
Appendix B: ACSM Absolute and Relative Contraindications to Resistance Training and Testing	46
Appendix C: Medical History Questionnaire	47
Appendix D: AHA/ACSM Health/Fitness Facility Pre-participation Screening Questionnaire	48
Appendix E: George Non-Exercise Test.....	49
Appendix F: National Strength and Conditioning Association Estimated 1RM Table ..	51
Appendix G: Borg’s Ratings of Perceived Exertion (RPE)	53

LIST OF TABLES AND FIGURES

<i>Figure 1- Study Visits</i>	<i>6</i>
<i>Figure 2- EPOC Trend BFR (20 Minutes).....</i>	<i>13</i>
<i>Figure 3- EPOC Trend TRAD (20 Minutes)</i>	<i>13</i>
<i>Figure 4- EPOC Trend BFR vs TRAD (20 Minutes)</i>	<i>14</i>
<i>Figure 5- EPOC KCALS (BFR vs. TRAD, All Subjects).....</i>	<i>15</i>
<i>Figure 6- Respiratory Exchange Ratio (Mean \pm Standard Deviations) Over Period.....</i>	<i>16</i>
<i>Figure 7- Respiratory Exchange Ratio Through EPOC, All Subjects.....</i>	<i>17</i>
<i>Table 1- Demographic Data.....</i>	<i>10</i>
<i>Table 2- Anthropometric Data.....</i>	<i>11</i>
<i>Table 3-Metabolic Data BFR and TRAD (Trained vs Untrained)</i>	<i>12</i>
<i>Table 4- Oxygen Consumption and RPE per Sets of Exercise BFR and TRAD</i>	<i>15</i>
<i>Table 5- Substrate Utilization (Mean \pm Standard Deviations) via RER.....</i>	<i>17</i>

Part I

INTRODUCTION

Much remains to be understood about how the body recovers following exercise. One aspect of recovery that is often investigated is Excess Post-exercise Oxygen Consumption (EPOC), which is measured as the duration and amount of increased oxygen uptake following activity.¹ This is accompanied by increased metabolic function and cellular repair, which helps speed the body's return to homeostasis. While it is most commonly associated with aerobic exercise, EPOC transpires following resistance exercise as well.² However, a standardized method to quantify EPOC following resistance exercise has yet to be established.

Resistance exercise results in chemical and physical changes in the muscle fiber that leads to an increase in oxygen uptake (VO_2) during the recovery period. Changes in substrate utilization, specifically a shift towards lipid oxidation, will result in an increase in VO_2 .^{3,4} Additionally, resistance training results in changes at the cellular level, particularly cell mitochondria, which are responsible for the mechanisms affecting O_2 consumption.⁵ Energy expenditure during exercise and aerobic capacity can also affect the quantity and duration of EPOC.^{2,4,6,7} Individuals with a greater muscle mass will have a larger energy expenditure, and thus an increased EPOC following exercises of similar intensity.² Thus, comparisons can be made between individuals with different levels of lean mass and EPOC in a resistive exercise.

Blood Flow Restriction (BFR) training has previously been used to increase intensity during exercise by limiting the return of venous blood from a limb during activity.^{1,8-10} This can be achieved utilizing wraps or cuffs placed at the proximal end of the limb.¹¹⁻¹⁴ No deficits in neuromuscular function or torque have been noted between BFR and normal conditions. Thus, even though there were changes in the load and number of repetitions performed, similar levels

of fatigue were felt along with objectified decreases in torque, regardless of whether BFR was used or not.¹⁵ Currently only one study has investigated the effects of BFR on EPOC. The intensifying effect of BFR was shown with treadmill walking; eliciting greater oxygen consumption with BFR both during exercise and recovery.¹ The relationship between BFR and EPOC following resistance training, has yet to be examined.

Therefore, the purpose of this study was threefold: 1) to compare EPOC between a low-intensity back squat exercise utilizing BFR to that of a traditional high-intensity back squat exercise, 2) to examine substrate utilization throughout rest, exercise, and recovery, and 3) to compare EPOC between trained and untrained individuals following resistance exercise.

METHODS

Research Design

A two-group repeated measures design was used to assess the acute effects of low-intensity squat exercise with BFR compared to a traditional high-intensity squat exercise on EPOC. The metabolic variables of interest in this study included: volume of oxygen uptake (VO_2), respiratory exchange ratio (RER) to determine substrate utilization, as well as the calculated metabolic variable, EPOC. The independent measures of this study were the condition (low-intensity back squats with BFR or high-intensity back squats) and training level (trained or untrained).

Participants

Seventeen healthy males between 18 and 35 years old were included in the study and were categorized as either trained (N=9) or untrained (N=8). Trained participants were defined as those that have participated in regular resistance training for at least one hour per day, three days a week, and consecutively over the past three months. Untrained individuals had not participated in regular resistance training over the last three months.

Only individuals classified as low risk by the ACSM were included in this study. Exclusionary criteria consisted of: absolute or relative contraindications to resistance training according to the American College of Sports Medicine (ACSM), as well as any contraindications to BFR (diagnosed hypertension, arrhythmia, ischemic changes in heart, diabetes, or BMI greater than $30 \text{ kg}\cdot\text{m}^{-2}$).^{16,17} Additionally, individuals with facial hair that interfered with the Hans Rudolph V2 mask (Shawnee, KS) were asked to shave or were not enrolled in the study.

Study Visits

Participants completed three study visits. The initial visit included a three-repetition max (3RM) squat, the subsequent sessions featured either a traditional high-intensity or low-intensity with BFR back squat exercise (see Figure 1). The three testing sessions were each separated by one week.

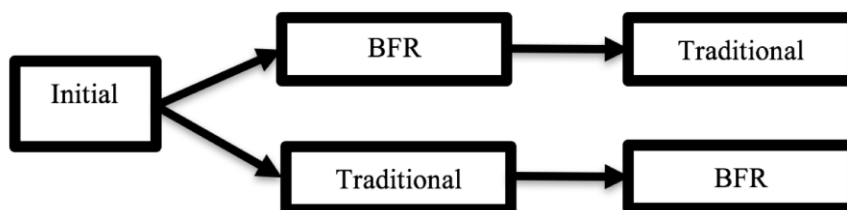


Figure 1- Study Visits

Initial Visit

Participants completed the informed consent process including a verbal presentation by one of the researchers, outlining the purpose, procedures, expectations, benefits, as well as potential risks. All participants then had the opportunity to read and sign the informed consent form approved by the university's Human Studies Program (Appendix A), ACSM Absolute and Relative Contraindications to Resistance Training and Testing (Appendix B), as well as a medical history (Appendix C), the AHA/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire (Appendix D) and the George Non-Exercise Test Questionnaire (Appendix E).¹⁸ Anthropometrics were also collected during this visit, consisting of: height (Ht),

body mass (BM), blood pressure (BP), thigh girth, and body composition as assessed by skinfold measurements. Participants were also familiarized with the proper form for barbell back squats if needed and 3RM testing was conducted.

Anthropometric Testing

Height was assessed using a wall mounted stadiometer (Seca 222, Chino, CA) and measured to the nearest 0.1 cm. Body mass was assessed using a “Certifier” balance beam scale (Detecto Model 442, Webb City, MI) measured to the quarter pound and converted to kilograms. Girth was assessed at the distal, mid-point, and proximal thigh using a Gulick tape measure according to the methods described by Lohman et al..¹⁹

Skinfold thickness was assessed, by the same researcher, using at 3 sites (chest, abdomen, and thigh) measurement (Lange Instruments, Santa Cruz, CA) and body fat percentage was calculated using the Jackson and Pollock formula (body density) and the Brozek equation (percent body fat).^{20,21} To help prevent researcher bias as well as to allow interstitial fluid to return to the tissues, measurements were collected on the right side in a rotating order. Measurements were performed at least twice and those that differed by two millimeters or more were measured a third time with the mean of the measurements used.

3RM Squat Testing

Estimated 1RM from low repetition (3 to 5 repetitions) testing has been shown to be highly correlated ($r=0.99$) with actual 1RM for lower extremity strength testing.²² If needed, participants were instructed in the proper technique for the back squat prior to 3RM testing. Participants completed one warm-up set of 5 to 10 repetitions with a self-selected light to moderate load, followed by another warm-up set of 5 repetitions with a self-selected moderate load. The load was then increased and the participant was instructed to perform 3 repetitions, if the participant completed the lift, they rested for four minutes before another attempt was made

with increased weight.²³ The participant continued this process until they were unable to complete a lift, at which point their last completed lift was used to estimate their 1RM using the National Strength and Conditioning Association's 1RM Table (Appendix F).²³

Testing Sessions

Participants were asked to avoid resistance training, non-steroidal anti-inflammatory medications, alcohol, tobacco, supplements and other medication for 3 days before the testing sessions.^{24,25} Utilizing the volume load method, testing sessions were designed to be volume matched (repetitions*weight, both protocols within 1%).²⁶ To confirm that blood flow restriction would be safe for the subjects, at the start of each session blood pressure was measured using an automated blood pressure cuff following five minutes of seated rest (Model HEM-907XL, Omrom Healthcare Europe B.V., Netherlands). Participants sat with their feet on the floor and their arm supported, with the cuff on the right arm. The proper cuff size was used for each participant to avoid incorrect blood pressure measurements.²⁷

Traditional Squats

After a five-minute self-selected warm-up, participants were then set up to the metabolic cart to continue testing. Exercise consisted of four sets of eight repetitions at 70% of estimated 1RM with 3 to 5 minutes of rest in between sets.¹⁸ Borg's Ratings of Perceived Exertion (RPE) were collected before and after each set of squats(Appendix G).²⁸ Including EPOC data collection, the traditional squat testing took approximately one hour.

Low-Intensity Squats with Blood Flow Restriction

Participants performed a self-selected warm-up prior to performing their initial squat set. Blood Flow Restriction was achieved through the use of elastic knee wraps (78 inch, Harbinger Fitness, Durham, North Carolina), which have been shown to occluded venous, but not arterial, blood flow.¹¹⁻¹⁴ The elastic wraps were applied at the most proximal portion of the thigh at a

perceived pressure of 7 out of 10 (tight, but not painful).¹¹⁻¹⁴ To ensure that arterial occlusion had not occurred distal pulse was confirmed by posterior tibialis palpation. If a pulse was not detectable, the wrap was loosened until it was detectable. Participants then performed 4 sets of squats at 30% of estimated 1RM.^{11,25} The first set consisted of 30 reps, followed by three sets of 15 reps.^{11,25} There were 90 seconds of rest between sets.^{11,13,25} Borg's Ratings of Perceived Exertion were collected before and after each set of squats (Appendix G). Total time for this session was approximately one hour with EPOC data collection.

Metabolic Data

Metabolic data (oxygen consumption, carbon dioxide production, ventilation) were collected on a TrueOne 2400 metabolic cart (Parvomedics, Sandy, UT) during the exercise testing sessions, with values averaged over 10 second intervals. Participants were fitted with a Hans Rudolph V2 mask attached to a one-way non-rebreathing valve to collect expired air. Five minutes of stable resting data were collected prior to exercise to serve as a baseline; data were also collected during exercise and for 20 minutes following exercise.

The magnitude and duration of EPOC determined following exercise was calculated as follows. The method utilized measured the duration of EPOC from the end of exercise until the VO_2 returned to within one standard deviation of its resting value for two straight minutes.¹ The area under the curve was then calculated using the trapezoidal method to determine the magnitude of EPOC. The trapezoidal method to determine the magnitude of EPOC works by approximating a known integral. The area under the curve is analyzed by calculating the area of the individual trapezoids used to approximate the integral. The more trapezoids under the curve, the more accurate the approximation; and if performed correctly, it can achieve a precise measurement of EPOC.²⁹ Magnitudes of EPOC were converted to kilocalories (kcal) to actualize the amount of energy expended during recovery.

Statistics

Statistics were performed using SPSS version 24.0 (IBM, Armonk, New York) with the significance level set at $p < 0.05$. Differences between the duration and amount of EPOC for the two testing protocols (low-intensity with BFR vs. high-intensity) and between groups (trained vs. untrained) were assessed using two by two repeated measures analysis of variance (ANOVA). Repeated measures ANOVA were utilized to determine differences in substrate utilization between the BFR and TRAD conditions.

RESULTS

Participants

Nineteen participants were recruited for this study, however, two withdrew from the study before completing both testing sessions and were removed from analysis. Of the remaining 17 participants, 9 were classified as trained and 8 were classified as untrained. Participants had a mean age of 25.3 ± 2.3 years old. The mean height was 177.4 ± 5.9 centimeters and mean body mass was 77.9 ± 10.9 kilograms, resulting in a mean BMI of $24.8 \pm 3.5 \text{ kg/m}^2$. The mean estimated $\text{VO}_{2\text{MAX}}$ from the George non-exercise questionnaire was $50.2 \pm 4.9 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Anthropometric data for trained and untrained participants as well as means are presented in Table 1.

Table 1- Demographic Data

Demographic data	Overall	Trained	Untrained
Enrolled	19	11	8
Completed n	17	9	8
Age (yrs)	25.3 ± 2.3	24.4 ± 0.7	26.3 ± 3.0
Height (cm)	177.4 ± 5.9	177.8 ± 6.5	176.9 ± 5.6
Body Mass (kg)	77.9 ± 10.9	82.4 ± 8.2	73.0 ± 12.1
Body Mass Index	24.8 ± 3.5	26.1 ± 2.2	23.4 ± 4.2
Estimated $\text{VO}_{2\text{MAX}}$ ($\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	50.2 ± 4.9	50.1 ± 4.4	50.3 ± 5.7

cm: centimeters, kg: kilograms

Anthropometrics

No significant differences were noted in the trained and untrained groups when evaluating the variables of height, BM, BMI, BF%, Systolic BP (SBP), Diastolic BP (DBP), and resting HR ($p>.05$). There were significant differences in proximal and mid-thigh girth measurements with trained being greater than untrained ($p<.05$). Also, the resistance for the 3RM back squat was significantly greater in the trained (291.1 ± 71.3 lbs) compared to untrained (186.3 ± 52.8 lbs) group ($p<.05$, see Table 2). Additionally, there was a trend towards differences between groups for body mass, lean body mass, distal thigh ($p<0.10$).

Table 2- Anthropometric Data

Anthropometric Data	Overall	Trained	Untrained	Statistical Significance
Body Mass (kg)	77.9 \pm 10.9	82.4 \pm 8.2	73.0 \pm 12.1	$F(1,16) = 3.591, p=0.078$
BMI	24.8 \pm 3.5	26.1 \pm 2.2	23.4 \pm 4.2	$F(1,16) = 2.803, p=0.115$
BF %	12.9 \pm 4.4%	13.3 \pm 4.8%	12.5 \pm 4.0%	$F(1,16) = 0.137, p=0.717$
Lean Mass (kg)	67.8 \pm 9.14	71.37 \pm 7.29	63.78 \pm 9.76	$F(1,16) = 3.343, p=0.087$
SBP (mmHg)	121.1 \pm 6.5	120.6 \pm 8.5	121.8 \pm 3.6	$F(1,16) = 0.135, p=0.718$
DBP (mmHg)	72.52 \pm 5.5	71.8 \pm 6.0	72.6 \pm 5.1	$F(1,16) = 0.096, p=0.761$
Resting HR (BPM)	68.2 \pm 12.5	67.6 \pm 10.3	69.0 \pm 15.3	$F(1,16) = 0.054, p=0.820$
Distal Thigh Girth (cm)	39.1 \pm 2.5	40.1 \pm 1.9	37.9 \pm 2.8	$F(1,16) = 3.649, p=0.075$
Mid-Thigh Girth (cm)	56.8 \pm 5.3	59.6 \pm 3.6	53.5 \pm 5.3	$F(1,16) = 7.941, p<0.013^{**}$
Proximal Thigh Girth (cm)	59.6 \pm 5.0	62.0 \pm 3.5	57.0 \pm 5.1	$F(1,16) = 5.825, p<0.029^{**}$
3RM Back Squat (lbs)	241.76 \pm 81.7	291.1 \pm 71.3	186.3 \pm 52.8	$F(1,16) = 11.599, p=0.004^{**}$
30% 1RM (lbs)	78.8 \pm 26.1	94.33 \pm 23.4	61.3 \pm 16.4	$F(1,16) = 0.914, p=0.005^{**}$
30% 1RM (kg)	35.8 \pm 11.9	42.87 \pm 10.6	27.8 \pm 7.6	$F(1,16) = 0.914, p=0.005^{**}$
70% 1RM (lbs)	183.4 \pm 61.5	220.3 \pm 54.6	141.9 \pm 38.9	$F(1,16) = 0.749, p<0.004^{**}$
70% 1RM (kg)	83.4 \pm 28.0	100.15 \pm 24.8	64.5 \pm 17.7	$F(1,16) = 0.749, p<0.004^{**}$

kg: kilograms; BMI: Body Mass Index; BF %: Body Fat Percentage; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; mmHg: millimeters of mercury; HR: Heart Rate; BPM: Beats Per Minute; cm: centimeters; lbs: pounds

** denotes statistically significant data

Metabolic Data

No significant differences were found in resting oxygen consumption between trained or untrained groups prior to the exercise session in either the BFR or TRAD conditions ($p=0.721$ and 0.556 respectively). There was no main effect for treatment, of BFR on EPOC. However, there was a significant difference in EPOC time between trained and untrained participants in the BFR condition ($p<.05$). Approaching significance, in the BFR condition, EPOC magnitude was higher in those participants that were trained compared to untrained ($p=.062$). In the TRAD condition, there was a significant difference in EPOC magnitude between the trained ($20.26\pm6.80\text{kcal}$) and the untrained ($12.76\pm5.89\text{kcal}$) group ($p<.05$). A comparison of metabolic data categorized by condition and group can be seen in Table 3. A visual representation of EPOC (20 minutes) between BFR and TRAD can be seen below in Figures 2 and 3 with an overlap of the two graphs in Figure 4.

Table 3-Metabolic Data BFR and TRAD (Trained vs Untrained)

Metabolic Data BFR and TRAD				
	Overall	Trained	Untrained	Statistical Significance
BFR				
Resting VO_2 (L/min)	0.274 ± 0.070	0.280 ± 0.054	0.267 ± 0.088	$F(1,16)=0.133, p=0.721$
EPOC Magnitude (kcal)	18.07 ± 8.20	21.54 ± 8.24	14.17 ± 6.57	$F(1,16)=4.080, p=0.062$
EPOC Time (min)	14.82 ± 6.12	17.98 ± 4.62	11.26 ± 5.81	$F(1,16)=7.052, p<0.05^{**}$
TRAD				
Resting VO_2 (L/min)	0.331 ± 0.143	0.351 ± 0.179	0.308 ± 0.094	$F(1,16)=0.363, p=0.556$
EPOC Magnitude (kcal)	16.73 ± 7.29	20.26 ± 6.80	12.76 ± 5.89	$F(1,16)=5.836, p<0.05^{**}$
EPOC Time (min)	14.16 ± 5.78	14.86 ± 5.74	13.37 ± 6.11	$F(1,16)=0.271, p=0.611$

L: liters; kcal: kilocalories; min: minutes; EPOC: excess post-exercise oxygen consumption; BFR: blood flow restriction; TRAD: traditional

** denotes statistically significant data

Figure 2- EPOC Trend BFR (20 Minutes)

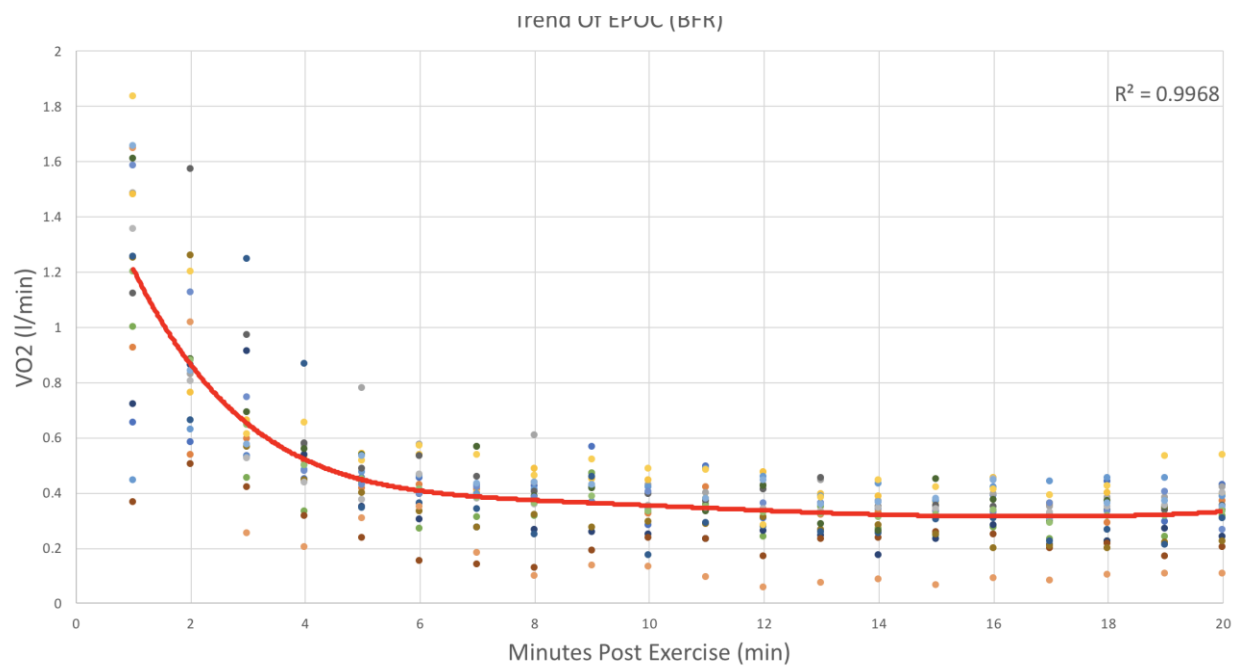


Figure 3- EPOC Trend TRAD (20 Minutes)

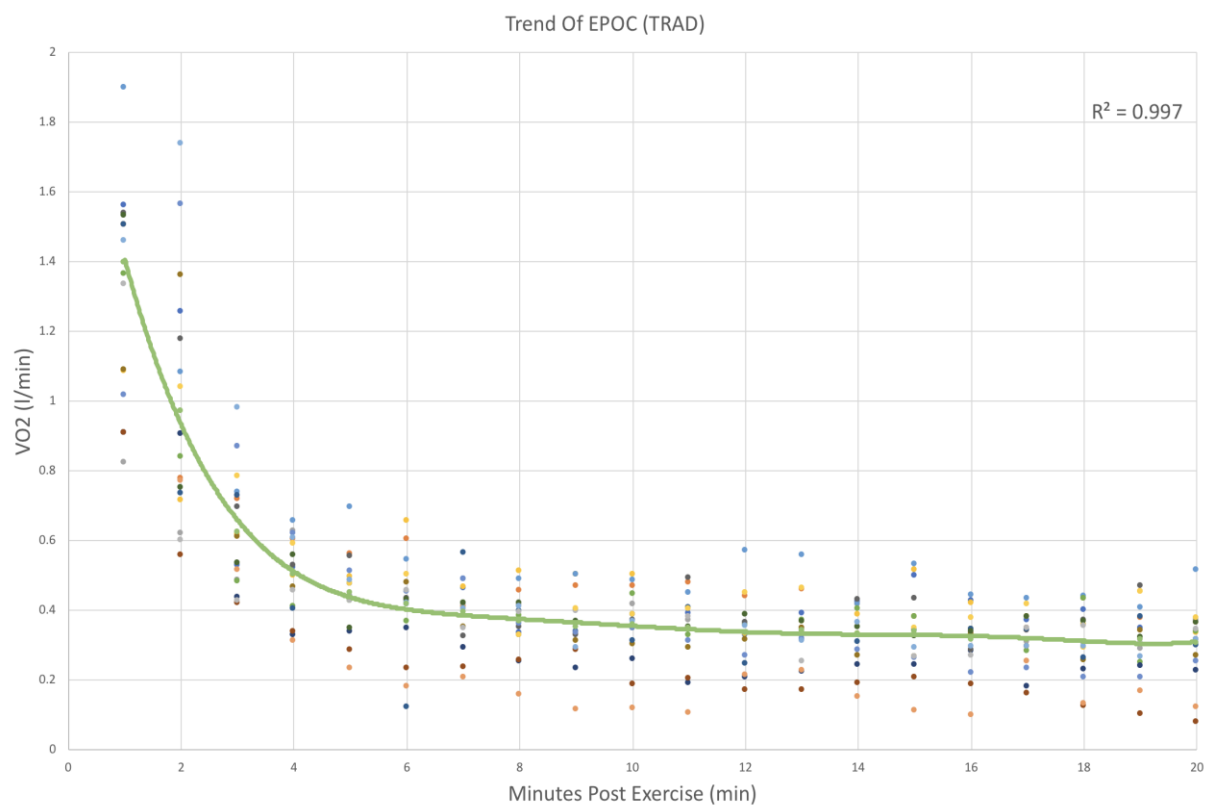
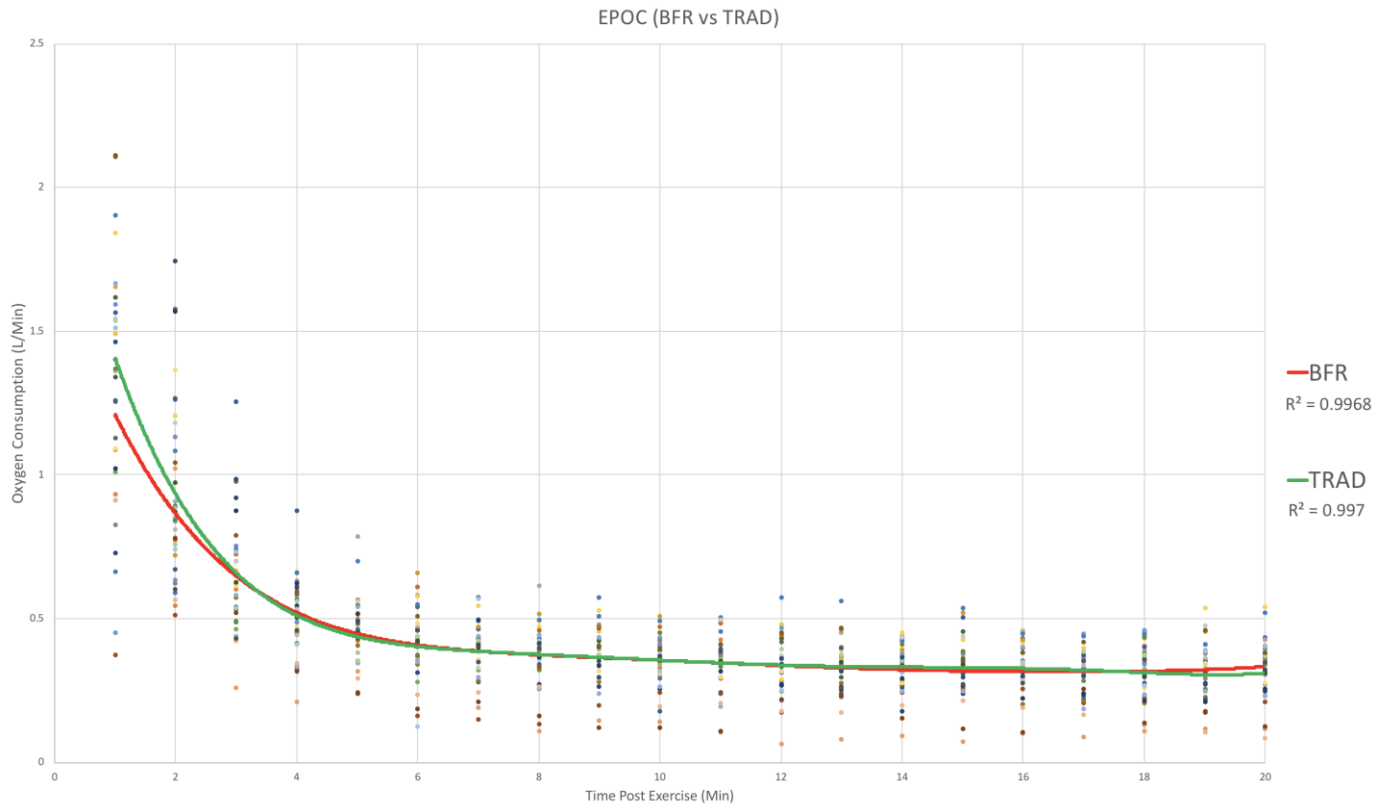


Figure 4- EPOC Trend BFR vs TRAD (20 Minutes)



liters of oxygen in the BFR condition, comparatively the TRAD condition consumed 0.472 liters of oxygen accounting for a 65.6% difference in the first set. The majority of RPEs (96%) between condition for all measures (legs, chest and breathing, and overall) were greater in the BFR state compared to the TRAD state. Two measures, chest and breathing and overall, were greater in the TRAD condition compared to the BFR condition during the 4th set of exercise. Oxygen consumed and RPE per set by condition can be seen in Table. 4

Figure 5 below displays a comparison of the magnitude of EPOC measured in kcals between the BFR as well as the TRAD condition over the full EPOC collection of 20 minutes. It can be seen that energy expenditure reaches its peak at the five-minute mark in both conditions. Both conditions then decrease exponentially to the culmination of the collection.

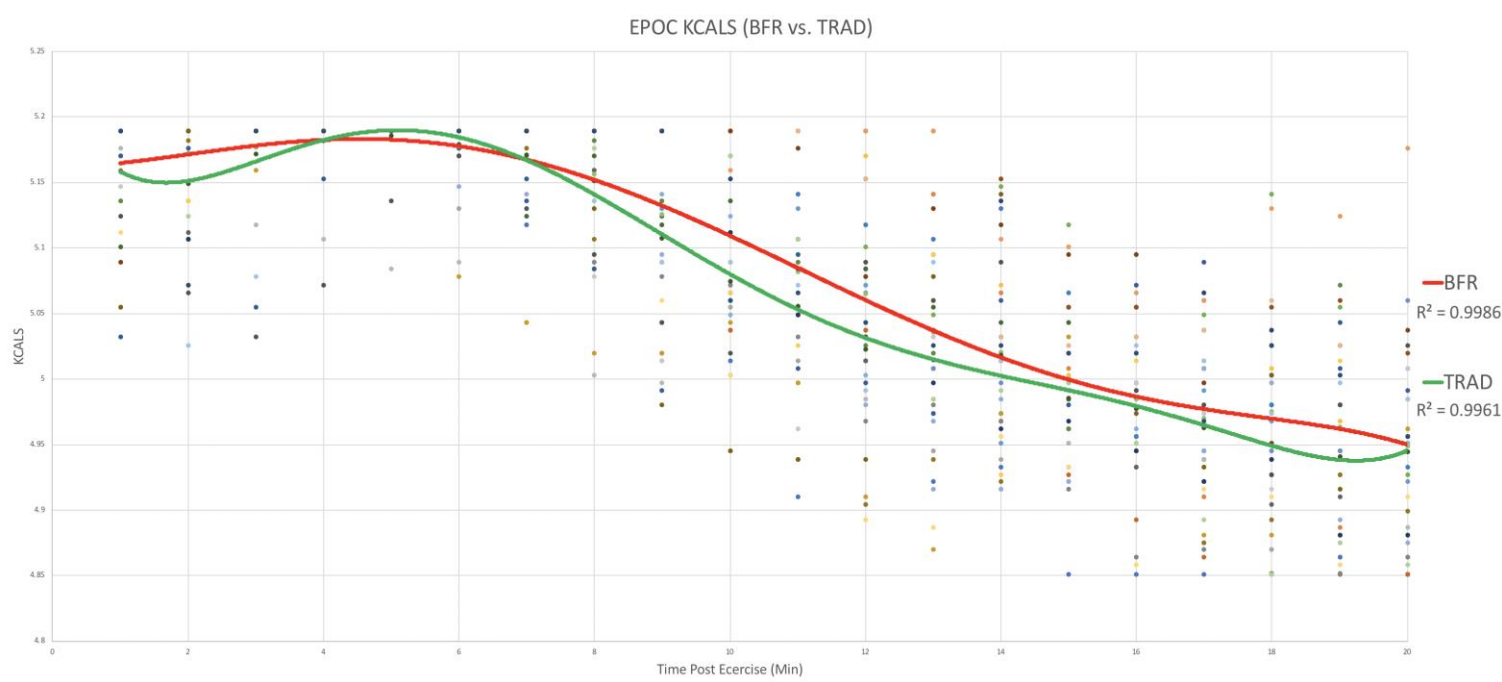
Table 4- Oxygen Consumption and RPE per Sets of Exercise BFR and TRAD

Absolute Oxygen Consumption and RPE (BFR)												
	O2 Consumed (l)			RPE Legs			RPE Chest			RPE Overall		
Set 1	1.372	±	0.568	12.3	±	2.6	11.9	±	2.2	12.2	±	2.2
Set 2	0.733	±	0.317	13.4	±	2.5	13.1	±	1.7	13.3	±	1.8
Set 3	0.736	±	0.310	14.2	±	2.7	13.8	±	2.4	14.0	±	2.3
Set 4	0.674	±	0.348	15.1	±	2.8	14.4	±	2.6	14.6	±	2.7
Total	3.516	±	1.416									

Absolute Oxygen Consumption and RPE (TRAD)												
	O2 Consumed (l)			RPE Legs			RPE Chest			RPE Overall		
Set 1	0.472	±	0.225	10.8	±	2.1	11.5	±	1.9	11.2	±	2.0
Set 2	0.486	±	0.205	12.5	±	2.1	12.7	±	1.8	12.6	±	1.8
Set 3	0.494	±	0.188	13.6	±	2.1	13.7	±	2.0	13.6	±	2.1
Set 4	0.468	±	0.181	14.6	±	2.3	14.8	±	2.0	14.8	±	2.1
Total	1.920	±	0.722									

RPE: ratings of perceived exertion; BFR: blood flow restriction; TRAD: traditional

Figure 5- EPOC KCALS (BFR vs. TRAD, All Subjects)



Respiratory Exchange Ratio and Substrate Utilization

Figure 6 shows the average RER during each period of rest and exercise. There were no significant differences for RER or substrate utilization during resting, set one, set three, set four, or EPOC. However, during the second set there was an 11% spike in RER in the BFR condition compared to the TRAD condition (1.346 ± 0.133 and 1.190 ± 0.126 respectively, $p=.002$), but this did not significantly affect substrate utilization. Respiratory exchange ratios were applied to estimate substrate utilization via a respiratory quotient table.³⁰ The RER values for resting, sets, and EPOC averages, as well as carbohydrate (CHO) and fat (FAT) percentages can be seen in Table 5. Figure 7 illustrates RER over the period of time after exercise in which EPOC was collected (20 mins). It can be observed that in the EPOC trends were similar in each condition.

Figure 6- Respiratory Exchange Ratio (Mean \pm Standard Deviations) Over Period

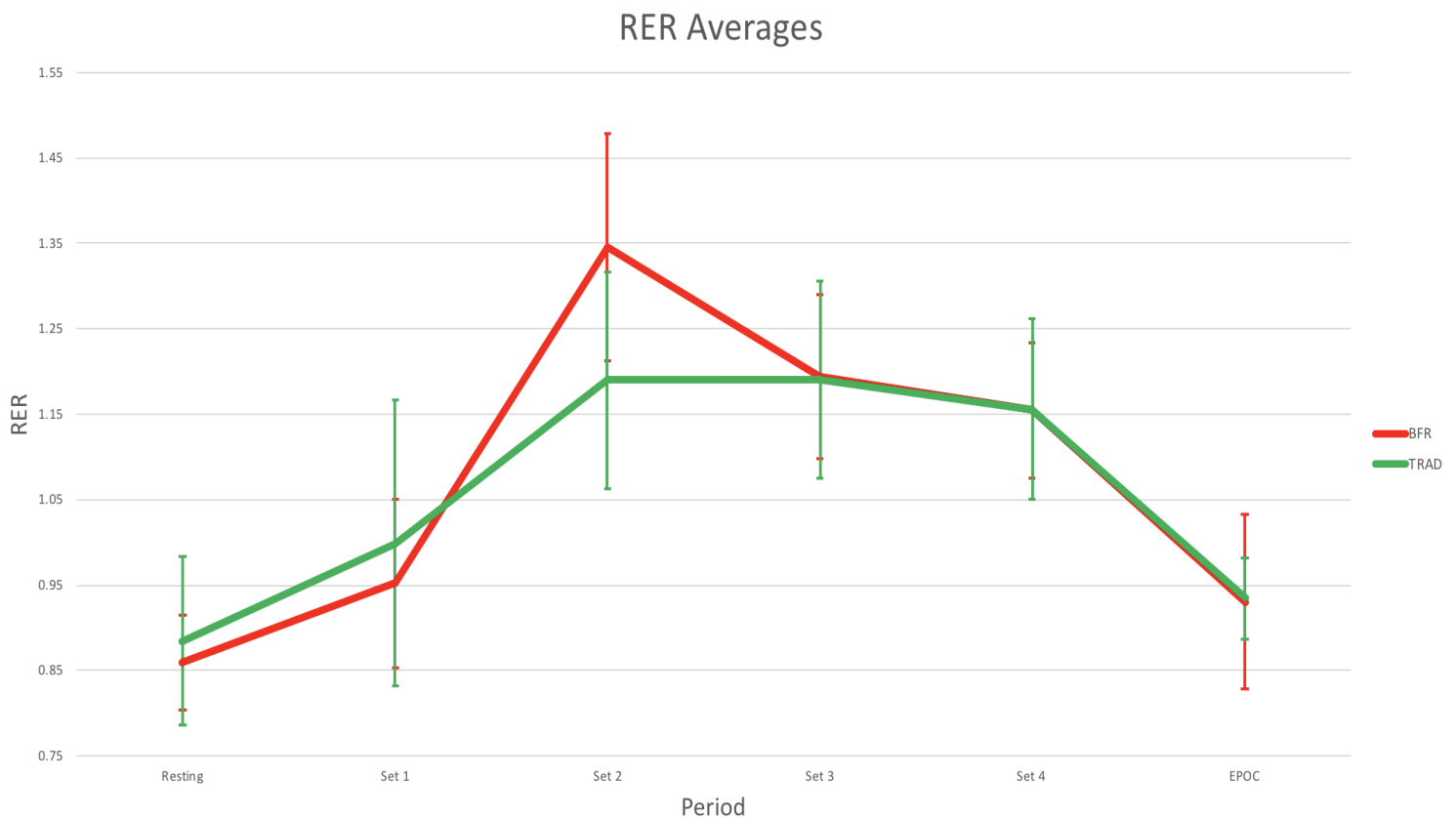
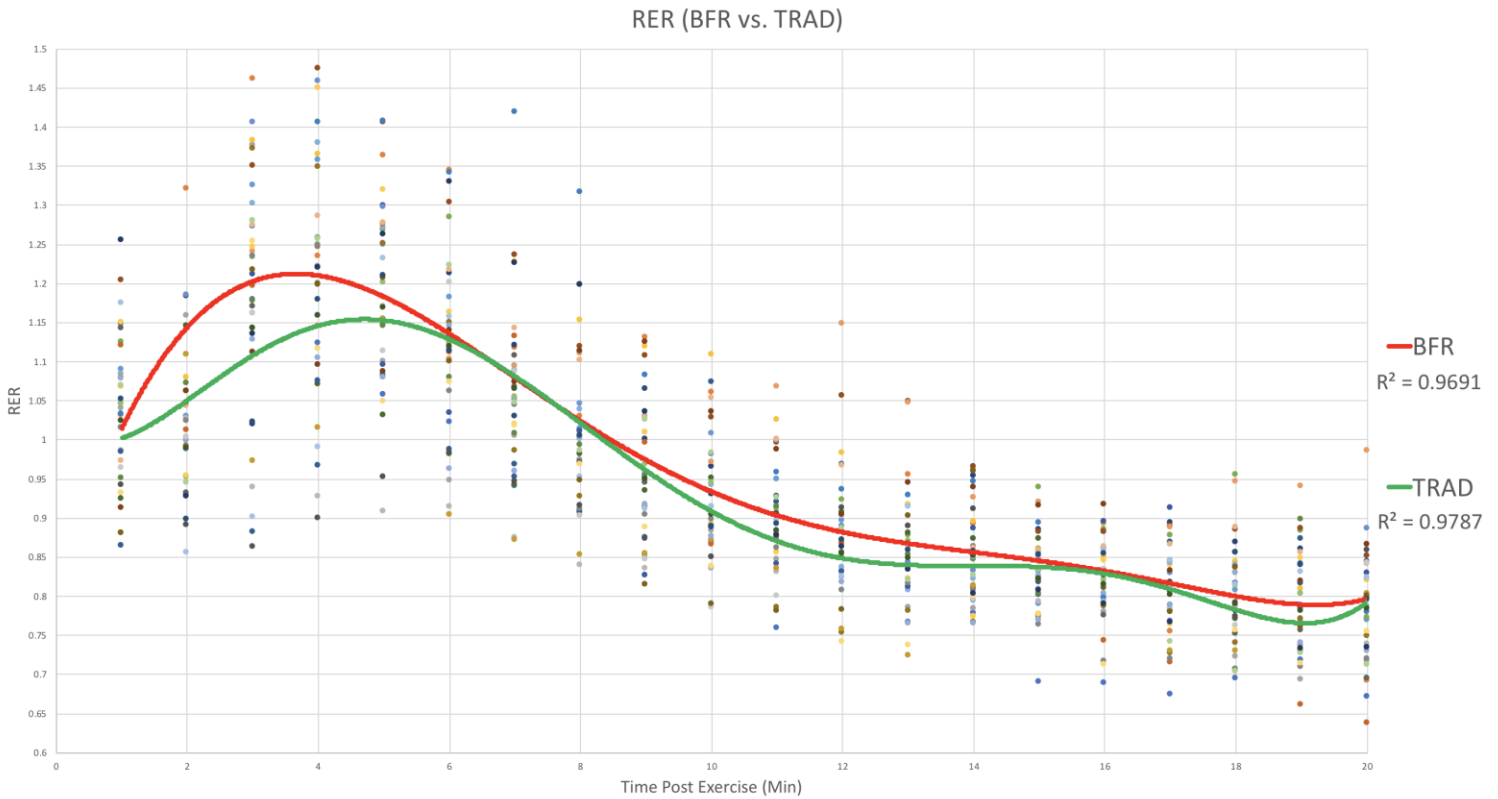


Table 5- Substrate Utilization (Mean \pm Standard Deviations) via RER

Substrate Utilization via Respiratory Exchange Ratio						
		RER	RER Statistical Analysis	CHO%	FAT%	Substrate Utilization Statistical Analysis
Resting	BFR	0.859 \pm 0.055	$F(1,16)=1.033, p>0.05$	53.82 \pm 18.59	46.18 \pm 18.59	$F(1,16)=0.703, p>0.05$
	TRAD	0.884 \pm 0.099		59.39 \pm 27.26	40.61 \pm 27.26	
Set 1	BFR	0.952 \pm 0.099	$F(1,16)=1.679, p>0.05$	78.94 \pm 24.67	21.06 \pm 24.67	$F(1,16)=0.023, p>0.05$
	TRAD	0.999 \pm 0.168		77.88 \pm 28.86	22.12 \pm 28.86	
Set 2	BFR	1.346 \pm 0.133	$F(1,16)=14.067, p=0.002^{**}$	100.00 \pm 0.00	0.00 \pm 0.00	$F(1,16)=2.479, p>0.05$
	TRAD	1.190 \pm 0.126		98.72 \pm 3.71	1.28 \pm 3.71	
Set 3	BFR	1.194 \pm 0.096	$F(1,16)=0.026, p>0.05$	100.00 \pm 0.00	0.00 \pm 0.00	$F(1,16)=1.134, p>0.05$
	TRAD	1.190 \pm 0.116		99.69 \pm 1.26	0.31 \pm 1.26	
Set 4	BFR	1.155 \pm 0.079	$F(1,16)=0.133, p>0.05$	100.00 \pm 0.00	0.00 \pm 0.00	$F(1,16)=1.134, p>0.05$
	TRAD	1.156 \pm 0.105		99.60 \pm 1.65	0.40 \pm 1.65	
EPOC	BFR	0.930 \pm 0.102	$F(1,16)=0.220, p>0.05$	74.42 \pm 30.97	25.58 \pm 30.97	$F(1,16)=0.234, p>0.05$
	TRAD	0.935 \pm 0.048		77.91 \pm 13.27	22.09 \pm 13.27	

RER: respiratory exchange ratio; CHO%: percent carbohydrate utilized; FAT%: percent fat utilized

Figure 7- Respiratory Exchange Ratio Through EPOC, All Subjects



DISCUSSION

The two main significant findings were that: 1) overall EPOC had a longer duration in trained individuals compared to untrained individuals in the TRAD condition (17.98 and 11.26 minutes respectively), and 2) there was a greater magnitude of EPOC in the trained versus untrained group in the BFR condition (20.26 and 12.76kcal, respectively). These differences may be accounted for by the greater load lifted by the trained group. There was also an approximate 10kg difference in body mass with roughly an 8kg difference in lean mass between trained and untrained individuals, which approached significance. Mass differences, specifically lean mass, may account for the difference in energy expenditure during EPOC.² In the context of the present study, having greater muscle mass directly affected the work assigned, which has previously been shown to influence energy expenditure.²

Although conducted in aerobic walking, Mendonca et al. and found that BFR increased the magnitude of EPOC compared to the non-BFR condition.¹ This finding was not consistent with the study at hand. There were no significant main effects between conditions for EPOC, as the combined groups performed the same amount of work in both conditions; this may be due to the decreased external load within the BFR condition. Previously, Elliot et al. found that there was a similar caloric expenditure during EPOC following heavy resistance exercise (51 ± 31 kcal at 80% 1RM) compared to low resistance circuit training (48 ± 20 kcal at 50% 1RM), during 90 minutes of recovery.² Although they did not include BFR in their study, their results were consistent with the current findings where similar caloric expenditures during EPOC in the low-intensity with BFR back squat (18.07 kcal at 30% 1RM) and the high intensity back squat (16.73 kcal at 70% 1RM).

There was over a 45% greater difference in oxygen consumption during exercise in the BFR protocol compared to the TRAD protocol. This may be because of the greater number of repetitions in the BFR condition to ensure that the protocols were load matched. There was a less than 1% difference between the protocols comparing volume, meaning that with similar absolute loads BFR or the number of repetitions performed may be the cause of greater oxygen consumption.

Substrate utilization via RER in this study was congruent with previous studies. CHO utilization increased from resting through the end of the fourth set, and then decreased slightly during the EPOC stage for most participants.^{4,31} Farinatti et al. observed similar trends in their analysis of substrate utilization during resistance exercise.⁴ Additionally, Farinatti's study involved EPOC collection that spanned 90 minutes allowing for observation of substrate utilization until returning to baseline. However, their study did not include BFR training.

Blood flow restricted training could easily be implemented during rehabilitation to allow individuals to receive the same metabolic benefit of working out at a traditional high intensity exercise. This allows patients to work at a lower intensity with great benefit while still accommodating their injuries. Also, this is a technique that can be implemented in a regular workout routine for a healthy individual, it can be utilized to overcome a plateau or to change a daily routine. These methods have previously been proven to be low risk, as well as having beneficial effect on muscular strength and hypertrophy.^{11,16,17,24,32-34}

Major limitations in the study include the inability to control for a participant's lifestyle, equipment utilization, substrate conversion from RER below 0.7036 and greater than 0.996, and time chosen to collect EPOC. Although informed to abide by minor dietary, supplementation, and exercise restrictions there were no way to confirm compliance. Type II error cannot be ruled

out due to the relatively small sample and the low effect sizes reported. Also, the use of a conversion table to determine substrate utilization could be a potential source of error in that fat and carbohydrate percentages have an absolute zero according to the table, while physiologically that may not be the case. Lastly, the duration of the EPOC collection methodology may have been a source of error. As reported by Borsheim and Bahr, some researchers, including Smith et al. and Harms et al. utilized EPOC collection periods of 20 minutes.³⁵ However, the majority of papers reported in Borsheim and Bahr included EPOC durations much greater than 20 minutes.³⁵ Other data collections span from 30 minutes to greater than 24 hours, all of which was reported by Borsheim and Bahr.^{31,35-40}

SUMMARY AND CONCLUSION

There were no differences between the mode of exercise, BFR or TRAD, on the effect of EPOC as either a function of time or magnitude. However, there were significant differences between trained and untrained individuals most likely due to differences in lean body mass or the volume difference between the groups. No significant differences were seen in substrate utilization via RER in resting, exercise, or recovery. The only difference found between groups for RER or substrate utilization was in the second set of exercise, where there was a significantly different RER between the BFR and TRAD conditions, however this did not significantly affect substrate utilization. Based on the findings of the present study, it was concluded that: 1) EPOC was not affected after a low-intensity back squat exercise utilizing BFR compared to that of a traditional high-intensity back squat exercise, 2) there was no main effect between conditions for substrate utilization throughout rest, exercise, and recovery, 3) finally, it was concluded that training status may have an effect on EPOC magnitude or time.

PART II

Literature Review

Blood Flow Restriction (BFR)

As strength and conditioning continues to change on many fronts, be it, in a collegiate setting, professional setting, rehabilitation setting, or even among a recreational group there is always a want to be a part of current trends. Blood flow restriction has become one of those growing trends in both strength and conditioning and rehabilitation. There have previously been studies showing positive results BFR, with this, some mechanisms are still unclear. Further research apart from the subsequent literature will be needed to determine safety and efficacy.

Acute Blood Flow Restriction

Loenneke et al. (2012) examined the mechanisms in which BFR could be a stimulus, shifting fluid to increase muscle size, in the absence of exercise.²⁴ Ten individuals that were screened for exclusionary criteria participants sat on a table with their legs supported, knees fully extended, fully relaxed.²⁴ After a period of rest BFR cuffs were attached to the participants, inflation then occurred for five minutes, and was repeated four times with three minutes of rest in-between.²⁴ Muscle thickness (MTH) and surface electromyography (EMG) were measured four minutes into each inflation bout. Muscle thickness was defined as the distance from the adipose-muscle interface to the intermuscular interface.²⁴ There were significant increases in both vastus lateralis as well as rectus femoris muscle thickness after the BFR compressions.²⁴ Electromyography was collected, but never analyzed due to the fact that there was no muscle activation throughout the whole study.²⁴ This is of importance because this would show that if there is no muscular activation there was no implementation of exercise, but it was found that there was an increase in muscular thickness.

Loenneke et al. (2010) examined the physiological processes in which occlusion training would stimulate growth.¹¹ It was explained in the ACSM that a weight of at least 70% of an individual's 1RM is needed to reach muscular hypertrophy with results in strength gains.⁴¹ This manuscript went on to explain changes in metabolic pathways including anabolic growth factors, protein synthesis, heart shock synthesis, and nitric oxide synthesis.¹¹ It was found that occlusion training will actually increase protein synthesis three-fold immediately after exercise, this in turn increases the muscle hypertrophy response.¹¹ Nitric oxide (NO) is a molecule that can move through tissues and when increased can release growth factors to stimulate satellite cells.¹¹ When satellite cells are increased in activation there will be an increase in skeletal muscle production. Overall, these simple mechanisms lend to an increase in skeletal muscle production all coming from blood flow occlusion.

Loenneke et al. (2011) developed a manuscript to observe the potential safety issues with BFR.¹⁶ There are several measures that can be examined and assessed for safety. These include peripheral blood flow response, thrombosis, coagulation, nerve conduction velocity, and muscular damage. The BFR mechanism still remains relatively unknown.¹⁶ It has been found that some responses during exercise with BFR are closely related to that of regular exercise.¹⁶ Examining other measures, it is found that coagulation activity does not appear to increase during these low-intensity bouts of exercise with BFR.¹⁶ When it comes to nerve conduction rate, there is not a large amount of research, but there does not seem to be a negative effect in healthy subjects.¹⁶ Lastly, when it comes to muscle damage, there is no change in either creatine kinase or myoglobin content, both of which would indicate muscle damage after an acute bout of exercise.¹⁶ Overall, because of unknown mechanisms there needs to be ongoing research to ensure safety and this has been done in other research across the world.

Nakajima et al. (2006) continuing focus on safety conducted a study to understand the current state of BFR training in its origin of Japan.¹⁷ Utilizing a survey, 105 facilities untimely completed this to give rates of side effects as well as how the devices are used. Upon return of the surveys some key notes of the facilities are as follows: there is a multitude of uses and populations including sports, healthy persons, cerebrovascular diseases, orthopedic diseases, obesity, muscle disease, as well as hypertension and respiratory diseases.¹⁷ Training has taken place in those under 20 years old and those over 80 years old.¹⁷ Continuing focus on side effects the most common side effect was subcutaneous hemorrhaging (more frequent in arms than legs), it was observed in 13.1% of the cases of the over 27,000 people that BFR training has been used on, hemorrhaging diminished as time went on.¹⁷ Other side effects noted were that of numbness which occurred in 1.297% of participants, this was also a temporary side effect.¹⁷ Lastly, as previously mentioned, the rate of thrombus was minimal and was only observed in 7 participants (.055%), pulmonary embolism was noted in 1 participant (.008%), but there were no serious problems along with no actual diagnosis.¹⁷ Overall, the safety of BFR training with particular precautions would appear evident after a survey of such a vast range.

Cook et al. (2013) compared endurance and neuromuscular function in low load, high load, and low load with BFR resistance.¹⁵ With eight participants, each participated in three sets of dynamic knee extension to fatigue. Measurements included torque, central activation, electrically evoked torque, and muscle activation (collected with EMG).¹⁵ Overall it was found that the low load conditions exhibited lower levels of muscle activation, however, there were similar decreases in torque across all exercise loads.¹⁵ This because important in settings where a high load may not be available or even contraindicated, thus creating a need for a low load

exercise, adding BFR can create muscle strength with no neuromuscular differences to that of a traditional high load exercise.

Acute Blood Flow Restriction with Treadmill Walking

Abe et al. (2005) sought to investigate Kaatsu (BFR) walking and its acute and chronic effects on muscle size and strength.⁸ Utilizing 18 subjects with minimal aerobic training, nine were selected to a BFR condition with restriction at the proximal thigh and nine were selected to a control condition, in which, BFR was not used.⁸ Strength (1RM leg press and 1RM leg curl) as well as muscle area cross section estimation was measured before the exercise intervention. There was a three week walk training conducted for both groups. Training happened twice a day with at least four hours between sessions. Walking speed as well as duration were the same every session.⁸ It was found that strength increased by over five percent in each strength measurement in the BFR group compared to the unchanged control group. It was also found that the cross-sectional area of muscle and bone increased significantly in the thigh.⁸ Overall, the sheer increase of size is something that had been underreported in previous research and is something that could create positive implications for the outcomes of a resistance protocol with BFR.

Mendonca et al. (2014) examined BFR and interval walking and the effect that it would have on the net metabolic cost of locomotion, walking.⁹ Observing 18 healthy males acting as their own controls; their optimal walking speed was found. Shortly after, all participants underwent a walking protocol consisting of five trials of walking with conditions being BFR or non-BFR, this occurring on the second and third visit.⁹ Restriction was achieved utilizing a pneumatic cuff placed on the proximal thigh of both legs. Overall, it was found that BFR increases the net metabolic cost of locomotion through the mechanism of increasing gross VO_2 . This is of importance when introducing the topic of EPOC, the increase gross VO_2 could have

implications to increased oxygen need for metabolic function, in which EPOC is working to restore. This response, ventilatory response with/to BFR is so apparent that it effected walking economy.⁹

Sakamaki et al. (2011) utilized BFR to observe the changes in size of distal muscles that were restricted as well as proximal non-restricted muscles in the limb and trunk during walk training.¹⁰ Seventeen healthy males were randomly divided into a BFR walking group and a non-BFR walking group.¹⁰ All participants partook in the same walking protocol, this consisted of five- two minute bouts of walking at 50m/min, which is roughly 1.8mph, there was a one minute break between bouts.¹⁰ It was found that muscle hypertrophy is prompted in muscles distal to the flow restriction, being thigh in this case.¹⁰ There were no changes seen proximally, with an increase in iliopsoas muscle volume that was not statistically significant.¹⁰ Application of this information is continually pertinent to this study, muscle hypertrophy is just one measure seen that is changed with BFR, this giving validity to other measures that researchers have already experienced.

Acute Blood Flow Restriction with Resistance Training

Cook et al. (2007) examined the effect of a BFR protocol on muscle fatigue and compared those protocols to recommended resistance exercise intensity.⁴² With 21 males and females, each participated in 5 visits. Measures included isometric strength using a knee extension dynamometer. Participants performed sets of knee extension until failure, each set had a 90-second rest between them until three sets were completed.⁴² The BFR portion of the study focused on working a repetition number of 20% or 40% of the known failure. Lastly, there was an 80% workload conducted without BFR. Overall, it was found that the BFR protocols created much more fatigue for the participants compared to the high load protocols.⁴² This reiterates all

the previous statements of how using BFR at a lower load can create similar effects compared to that of a high load exercise.

Fitschen et al. (2014) created a two-part study in which researchers first wanted to observe the effects of continuous or intermittent BFR in a single bout resistance training.⁴³ The second study was created utilizing the results from the first study in which it was found that intermittent BFR created similar fatigue compared to continuous BFR; the second study examined a training period with continuous and intermittent BFR and its effects on skeletal muscle size and strength.⁴³ Both studies utilized 11 subjects in which the first study randomly assigned participants to different conditions of leg extensions: control, intermittent BFR, and continuous BFR.⁴³ Subjects in each condition were asked to perform single leg extensions until failure, this happened for four sets with 90-seconds of rest between.⁴³ As previously mentioned it was found that intermittent BFR created similar fatigue effects as continuous BFR. The second part of the study consisted of a five week, three days a week training period using continuous or intermittent BFR. It was found that continuous BFR elicited more pain for the participant. The repetitions to failure however did not differ.⁴³ Lastly, it was found that when it comes to strength this five week protocol created significant increases in strength even at a low load.⁴³

Yasuda et al. (2015) also examined the effects of low load resistance exercise with and without BFR on muscle swelling.⁴⁴ Ten men volunteered with a 1RM collected for each arm (arm curl). All subjects completed both arm curls with and without BFR for four sets, each set until exhaustion (this was defined as failure to keep up with a metronome).⁴⁴ Overall, regardless of BFR the low load exercise to fatigue promoted muscle swelling.⁴⁴

Neto et al. (2015) pursued to compare the hypotensive effect of resistance exercise with and without BFR.⁴⁵ Twenty-four men participated in the study, four protocols were put into place

including: a high intensity 80% 1RM exercise, a low intensity 20% 1RM exercise, a low intensity 20% 1RM exercise with BFR, and a control.⁴⁵ The exercises included a bicep curl and a tricep extension. Participants blood pressure data was collected before and after each session. Results showed that both the high intensity and low intensity with BFR exercise can be used to maximize the hypotensive effect of resistance exercise. The low intensity with BFR also showed improvements in diastolic blood pressure as well as mean blood pressure.⁴⁵ This study has great clinical application for those that may not be able to perform resistance exercise at a high intensity (80% 1RM), in which they can perform at 20% 1RM and achieve similar hypotensive results.

Madarambe et al. (2010) also focused on a low intensity BFR leg press and how the BFR would affect clot formation and the overall coagulation system.⁴⁶ After finding a 1RM leg press for the participants, they performed four sets of the exercise at 30% of the collected 1RM, sets were broken down as follows: 30, 15, 15, 15 following a 1:1 cadence.⁴⁶ The effect on the coagulation system was measured through blood sampling. After analysis, it was found that there was no effect of the BFR exercise on the measures that indicate change in the coagulation system.⁴⁶ This study speaks more to the safety of BFR, showing that there is not any blood coagulation issues is just the first step showing that BFR can be a safe alternative to high intensity exercise.

Suga et al. (2012) evaluated metabolic stress and fast-twitch muscle fibers during low intensity BFR exercise compared to high intensity exercise.⁴⁷ Twelve males participated in the study which included four exercise conditions (two exercises with BFR, continuous and intermittent and two exercises without BFR, high and low intensity) and a high intensity condition.⁴⁷ The experimental sessions consisted of three sets that were one minute long in which

30 repetitions of a plantar flexion exercise (heel raise) was performed. Low intensity was performed at 20% of a 1RM and high intensity was performed at 65% of a 1RM.⁴⁷ After exercise participants underwent P-magnetic resonance spectroscopy (P-MRS). Observing chemical shifts researches were able to determine metabolic stress after calculating intramuscular pH.⁴⁷ It was seen that metabolic stress in BFR conditions reach similar levels of that compared to high intensity exercise.⁴⁷

Practical Blood Flow Restriction (pBFR)

Loenneke et al. (2012) sought to provide an explanation for lower hormone response observed in BFR training as well as provide evidence that metabolic accumulation is not the only mechanism in BFR training.²⁷ Through two training session participants were randomized to either a control or BFR training, but ultimately participated in both the control and BFR sessions upon the second training session. Applying elastic knee wraps to nine participants (either first session or second session) accumulating in exercise testing consisting of five 2-minute bouts of walking at 75m per minute with a one minute rest between measuring whole blood lactate (WBL).²⁷ It was found that although WBL increase was statistically significant it cannot be considered a real finding because the minimal differences were not met.²⁷ This finding can lead to implications including that of other mechanisms that can effect BFR as well as allowing other research with BFR and resistance training to explain metabolite build up.

Lowery et al. (2014) assessed the effects of pBFR restriction on muscle hypertrophy.¹² A randomized cross over study was conducted on 20 college males with at least one year of resistance training experience.¹² Muscles targeted were the elbow flexors in an 8 week program that consisted of 4 weeks of BFR training.¹² To assess muscle thickness, direct ultrasound was used by a blinded researcher. Statistically speaking there were no difference in baselines among individuals ($p=.52$).¹² There were statistically significant increases in muscle thickness in the

BFR group no matter the weeks in which the training was performed, these effects occurred from both week 0 to week 4 ($p < .01$) as well as week 4 to week 8 ($p < .01$).¹² This plays importance because it shows that there can be similar hypertrophy effects in BFR training compared to high intensity training.

Luebbers et al. (2014) continued to observe pBFR training and its effects on muscular strength and size in a 7-week program implementing BFR with a strength training program with American football players.¹³ 72 players volunteered for the study and they were randomly divided into four training groups consisting of a traditional high intensity training more specific to football including bench press, overhead press, power clean, squats, and additional variations.¹³ The second group was a modified training group in which the core exercises were the same with the exclusion of the variations, the third group consisted of a supplemental training at 20% of a 1RM post a traditional high intensity session, lastly, the BFR with elastic knee wraps group performed squats and bench press.¹³ All participants were part of pre-tests and post-tests both split over 2 days; these tests included measurements of 1RM testing, limb girths, as well as body mass.¹³ It was found that those that participated in the traditional high intensity training, the supplemental training, as well as the practice BFR training had significant increases in 1RM squat.¹³ Occlusion did not play any role in size increases of either arm or thigh.¹³ These findings have implications in that there could be an increase in 1RM squat performance as well as the fact that elastic knee wraps would be a viable option for occlusion.¹³

Wilson et al. (2013) aimed to investigate the effects of low-intensity pBFR training on muscle activation, muscle swelling, and muscle damage.¹⁴ Twelve trained participants completed an exercise scheme at a low-intensity (30%) of their 1RM leg press.¹⁴ Groups for the study included a control as well as BFR group, however, both groups received wraps, the tension in the

wraps (venous occlusion vs. no tension) was the difference between the groups.¹⁴ All participants performed four sets including 30 repetitions for one set with three sets of 15 repetitions to follow.¹⁴ Measurements included ultrasound to determine muscle thickness, EMG to determine muscle activation, blood lactate, the visual analog scale to determine muscle soreness, as well as a force plate to measure peak vertical jump power.¹⁴ It was found that muscle thickness did increase from baseline in the BFR group ($p < .0001$), with no changes in the control; there was also a an increase in muscle activation ($p < .05$) with the BFR group comparatively.¹⁴ Twenty-four hours post exercise there was no increase in thickness in either group showing that there was no effect of BFR on muscle damage.¹⁴ As previously mentioned, BFR continues to show increase in hypertrophy and muscle activation.

Previous research has shown that there is an increase in hypertrophy and skeletal muscle production, as well as, overall muscle thickness after the utilization of BFR during resistance exercises.^{11,12,14,24} There have been proven methods that are provisionary viewed as safe.^{13,17} With this positive information there still have been a couple authors that continually explain that because of unknown mechanisms, continued research must be completed.^{16,27}

Excess Post Exercise Oxygen Consumption (EPOC)

With exercise there is increased ventilation, and several authors have studied the energy expenditure incurred because of these increases in ventilation^{1,2,4,6,7}. Excess post exercise oxygen consumption is measured through metabolic analysis. The importance of this measurement lies in what it tells a clinician about the energy expended not only post exercise, but during exercise as well.

Bloomer et al. (2005) created a study with the purpose to compare kcal expenditure and physiological responses of moderate duration resistance and aerobic exercise matched for

intensity and time.⁶ A random crossover design was used to compare expenditure of resistance and aerobic training, ten participants with prior resistance and aerobic experience were separated by weeks in which all participated in the resistance and aerobic groups.⁶ The squat protocol consisted of a brief warm-up, 70% of a 1RM weight was used, sets consisted of repetitions until muscular failure (5-12) there was then a rest period (90-120sec) this was repeated until the 30 minute training session was completed.⁶ The cycle protocol entailed a brief warm and then a workload was added to maintain an intensity equal to 70% of a previously recorded VO_2Max , workload was adjusted as needed.⁶ It was found that the energy cost of aerobic exercise exceeds that of resistance training when matched, with that being said, moderate duration resistance exercise does have the potential to meet the ACSM standards for physical activity and energy expenditure.⁶ It is important to note that this study continues on to recommend that a study of EPOC is very important due to the mechanisms of energy expenditure.⁶

Elliot et al. (1992) went out to measure EPOC in heavy-resistance training, low-resistance training, circuit-style training, and aerobic exercise.² Measures of the study included minute ventilation, oxygen concentration, carbon dioxide concentration, and heart rate.² Nine subjects were randomly assigned to four conditions including a control, 40 minutes of cycling, 40 of circuit training (low resistance; 50% 1RM), and 40 minutes of heavy resistance weight lifting (80% 1RM).² The resistance training exercise set included bench press, knee extension, leg curl, seated leg press, lat pull down, military press, seated row, and seated chest fly.² It was found that there are caloric differences. Of note, cycling and circuit training utilized more calories.² Of a greater note, the EPOC collected from both resistance measures, anaerobic exercises, were similar to that of the cycling, aerobic exercise.² The last piece of information of note is the explanation that EPOC is a measure that can be compared to muscle mass because

those with a greater muscle mass will perform greater work and will have greater energy expenditure.²

Farinatti et al. (2016) observed oxygen consumption during and after exercises performed with different muscle mass.⁴ Ten healthy men participated in the study all of which had previous resistance training.⁴ Measures of importance included VO_2 , RER and calculated EPOC. After collecting resting data participants performed a warm up with a subsequent exercise bout. The exercise bout included five sets of ten repetitions at a 15RM workload for both leg press and chest fly with a one minute rest between intervals.⁴ Respiratory measurements were taken for later analysis. Breath by breath points were averaged for the entire set as well as resting intervals; total VO_2 was collected by summing the values obtained during both the sets as well as the rest intervals.⁴ A 90-minute EPOC was collected and calculated, findings include a greater EPOC after leg press compared to chest fly, total VO_2 during EPOC was greater with larger muscle exercises (leg press). These findings are of importance when examining EPOC and its effects on resistance training to ensure that the correct exercise is used to gain the largest VO_2 measure during this post exercise phase.

Mendonca et al. (2015) continues to look at EPOC, but has now added the other measure of BFR. Seventeen male participants were divided into two groups, a BFR condition and a non-BFR condition, all exercise was aerobic walking.¹ Walking bouts consisted off five sets of three minutes at a speed calculated to each individuals leg length.¹ BFR condition underwent the same bouts with the addition of a pneumatic cuff placed at the most proximal portion of the leg and ultimately inflated to 200mmHg, this restriction was maintained for the entire bout of exercise.¹ Main measures included VO_2 , minute ventilation, heart rate, and respiratory exchange ratio. EPOC was later calculated as a function of two measures, time (min) and magnitude (mL and

kcal). EPOC time was measured as the end of exercise to the return of VO_2 to within one standard deviation of resting.¹ To find magnitude the area under the curve was integrated between resting and recovery VO_2 using the trapezoidal rule.¹ Overall it was found that EPOC magnitude was greater after BFR conditions compared to non-BFR conditions ($p < .05$).¹ This information is extremely valuable in that information for calculating EPOC as a function of time and magnitude is included as well as that there is no evidence that BFR can have an impact on EPOC in walking, while effect in resistance training is still unknown.

Vianna et al. (2014) sought to examine the comparison of VO_2 and heart rate in different types of resistance exercise.⁷ All participants ($n=14$) were males that had resistance training experience.⁷ Utilizing 1RM strength measurements in the half squat, bench, pull down, and triceps push downs, participants then performed repetitions at 80% of that 1RM until failure, there was a 60 minute recovery period between exercises.⁷ Data collected during the exercise included VO_2 , carbon dioxide production, and ventilation, recovery period data was also collected for five minutes post each individual set; heart rate was also collected throughout the exercise for later analysis of heart rate kinetics.⁷ In regards to EPOC and VO_2 there were several results of note; first, the highest VO_2 peak numbers were noted in those that performed the half squat, second, during the fifth minute of recovery between sets VO_2 values returned to that of the pre-exercise measures.⁷ The half squat elicited a greater EPOC than any other exercise.⁷ This article, like previous, give great insight to the methods of calculating EPOC and various ways in which it can be done, testing the different methods in comparison to each other could prove to be an interesting topic.

The previously mentioned literature demonstrates that resistance training can elicit similar effects on oxygen deficit compared to that of aerobic exercise.² Resistance exercise can

be used to obtain EPOC measurements that fluctuate based on load and duration.^{4,6} It also explains that there are variations in the way EPOC can be collected, but not explanations on which would be best.^{1,7} Excess post-exercise oxygen consumption following resistance exercise is still not fully understood and must be further examined.

There is currently a deficiency of research examining the effects of BFR on EPOC in a low-intensity resistance exercise compared to that following traditional high-intensity resistance exercise. Even further, this gap does not cover specifically the nature of a large multi-joint exercise. This area can be investigated simply through comparing both low-intensity resistance training to a traditional training program with the practical application of a BFR intervention. Additionally, comparisons can be drawn between trained and untrained participants to examine the effect training would have on EPOC. Lastly, as previously mentioned the measure of EPOC as a function of time and magnitude could lend to variance in calculations, it would be of interest to see if the different measures of calculations yield statistically significant results.

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Appendix A: Informed Consent

Subject Information and Informed Consent Form:

Researchers: Ronald Hetzler, PhD, FACSM
Morgan Kocher, MS, ATC
Tyler Held, BS, ATC

Institution Address: 1960 East West Rd. Honolulu, HI 96813

Phone Number: 808-956-9585 Off hours: 808-956-5555

Study Sponsor: Kinesiology and Rehabilitative Science Department
1337 Lower Campus Rd, PE/A 231
Honolulu, HI 96822

Protocol Title: Erythrocyte Oxidative Stress and Oxygen Consumption with Low-Intensity Blood Flow Restricted Resistance Exercise and Training

Protocol Number:

Date of Protocol:

INTRODUCTION TO RESEARCH STUDY

You have been asked to take part in a research study

This Subject Information and Informed Consent Form tells you about the study. The researcher will go over this with you and answer any questions you may have regarding the study. Ask your researcher to explain any words or information in this consent form you do not clearly understand. You should understand the purpose of the study, how taking part may help you, any potential risks to you, and what is expected of you during the study.

If you agree to take part, you will be asked to sign and date this consent form and will be given a signed and dated copy to keep. No one can force you to take part in this study. Even if you agree to take part now, you can decide otherwise and stop at any time without penalty or loss of benefits to which you would otherwise be entitled.

PURPOSE OF THE STUDY

The purpose of this study is to look at the oxidative stress response in red blood cells following low-intensity resistance training with practical Blood Flow Restriction and if this effect is changed with two weeks of resistance training. Additionally, this study will compare the oxygen consumption following two types of resistance training (traditional high intensity vs. low-intensity with practical BFR).

You have been asked to participate in this study because you are between 18 and 35 and have either not been performing regular resistance training for the past three months, or have not been

performing regular resistance training for the past three months and are considered as low risk for exercise as determined by the criteria set forth by the American College of Sports Medicine. You will be excluded from the study if you have diagnosed hypertension, arrhythmia, ischemic changes in the heart, a BMI greater than $30 \text{ kg}\cdot\text{m}^{-2}$, or meet any of the absolute or relative contraindications for resistance training and testing established by the American College of Sports Medicine.

DESIGN OF THE STUDY

If you agree to participate, you will be one of about 40 participants recruited from the University of Hawaii at Mānoa community. This study is open to male participants, between 18 and 35 years of age, who meet the study requirements.

Once you are found to be eligible to participate in the study, and you state that you want to take part in the study, you will be assigned a subject number.

DURATION OF THE STUDY

Once you are found to be eligible to participate in the study (during the Initial Visit), and you state that you want to take part, your participation will last for a minimum of 4 weeks (about 1 month), including the Initial visit. During this time, you will be required to visit the lab at least 9 times (initial visit, two pre-training testing sessions, four training sessions, one post-training testing session, and final visit).

SUBJECT RESPONSIBILITIES

If you decide to participate, there are certain rules you must follow before, during, and after the study period. Some are listed below, but there could be others that the study doctor will discuss with you:

It is very important that you tell your researcher all of the information you know about your health and medications you may be taking throughout the study period. If you do not tell the study doctor everything you know, you may be putting your health at risk.

You must follow all instructions given to you while you are participating in this study. If you do not, you may be removed from the study. If you are unsure about what you are supposed to do, ask the researcher.

STUDY PROCEDURES

Initial Visit

To help the researcher find out if you can participate, and to establish the level of resistance to be used in the study, you will need to perform an initial visit. After you sign the informed consent form and receive a copy of it, you will have several screening procedures done. Note that all of the procedures listed below may not be performed if at any point during the evaluation you fail eligibility. These procedures will include:

An interview about your medical history

A questionnaire about your health and if you are ready for physical activity

A questionnaire about your ability to perform physical exercise

Weight, height and vital sign measurement (blood pressure, thigh girth and skinfold measurements)

A three-repetition maximum for the back squat to estimate your back squat one repetition maximum (if you are unfamiliar with the back squat, instruction will be provided)

The researcher will review all of your medical information and findings from your Initial Visit and other entry criteria, as required by the study protocol, to ensure that you are eligible to

participate in this study before measuring your weight, height, and vital signs and conducting the three-repetition maximum back squat.

Restrictions During the Study

You will be asked to “fast”, which means not eating or drinking anything except water for at least one hour before the Testing Sessions. Additionally, you will be asked to avoid non-steroidal anti-inflammatory medications, alcohol, tobacco, supplements and other medication if possible for 3 days before each of the Testing Sessions. You should check with the researcher about any medication or health supplements you are taking during the study.

Testing Sessions

Within one week of the Initial Visit, you will be asked to come back to perform one of two testing sessions, with the other session completed within a week. At this visit it is important that you have eaten or drank nothing but water for one hour prior to your visit. Procedures at this visit will include:

About 200 μ L (about 4 drops) of blood will be collected from a free-flowing digit puncture taken at several points throughout the visit:

Prior to exercise

Immediately after exercise

30 minutes after exercise

Approximately 5-10 mL (1-2 teaspoons) of saliva will be collected from cotton balls that you have chewed on at three points during the visit

Prior to exercise

Immediately after exercise

30 minutes after exercise

Metabolic data will also be collected during exercise and for 30 minutes following exercise. In order for this to occur, you will be fitted with a mask to collect your expired air during and after testing.

The exercise protocol will be one of the following:

Four sets of eight repetitions at 70% of estimated one repetition maximum

One set of 30 repetitions, followed by three sets of 15 repetitions at 30% of estimated one repetition maximum with venous blood flow restriction

Training Sessions

You will be asked to come in four times over the course of two to three weeks for additional training sessions of resistance training using 30% of your estimated one repetition maximum with practical Blood Flow Restriction. These will be performed in the same manner as during the testing session, but without the blood draws before and after, and no metabolic data will be collected.

Post-training Testing Visit

At this visit it is important that you have eaten or drank nothing but water for one hour prior to your visit. Following the last of the training sessions you will come in for a final session of low-intensity resistance training with practical BFR. It will be similar to the Initial Testing session, but metabolic data will not be collected. Procedures at this visit will include:

About 200 μ L (about 4 drops) of blood will be collected from a free-flowing digit puncture taken at several points throughout the visit:

Prior to exercise

Immediately after exercise

30 minutes after exercise

Approximately 5-10 mL (1-2 teaspoons) of saliva will be collected from cotton balls that you have chewed on at three points during the visit

Prior to exercise

Immediately after exercise

30 minutes after exercise

The exercise protocol will consist of one set of 30 repetitions, followed by three sets of 15 repetitions at 30% of estimated one repetition maximum with venous blood flow restriction

Final Visit

Within a week of the last testing visit, you will be asked to come in one more time. Procedures at this visit will include:

Weight, height and vital sign measurement (blood pressure, thigh girth and skinfold measurements)

A three-repetition maximum for the back squat to estimate your back squat one repetition maximum (if you are unfamiliar with the back squat, instruction will be provided)

RISKS

Back Squat Exercise

The back-squat exercise utilized for this study may result in delayed onset muscle soreness following the first few visits. Once you become accustomed to the exercise load, you should not have any more increased soreness for the remainder of the study. During the back squat, your form will be monitored by the researcher and any deviations from the proper form will be corrected prior to the next repetition. It is still possible that some musculoskeletal injury may occur, but the intensity in the majority of sessions is rather low to help reduce this risk.

Practical Blood Flow Restriction

Other, less serious side effects were reported that occurred more frequently than the serious side effects and included: subcutaneous hemorrhage (13.1%), numbness (1.297%), cold feeling (0.127%), pain (0.040%), itch (0.024%), feeling sick (0.016%) and increased blood pressure (0.016%).

Blood Sample Collection

In addition to risks linked with the study, drawing capillary blood may cause local pain, bruising, occasional lightheadedness, fainting, and very rarely, infection at the site of the draw.

UNKNOWN/UNEXPECTED RISKS AND DISCOMFORTS

You may have a side effect that requires your researcher to take you off the study. You should contact your researcher immediately if you feel that you cannot tolerate participation in the study.

POSSIBLE BENEFITS OF THE STUDY

There is no guarantee that you will receive personal benefit from participating in this study, but it is possible that you may have some beneficial adaptations to training, such as increased strength and muscle mass. In addition, your participation may provide information that will increase the knowledge and information about low-intensity resistance training with BFR.

WITHDRAWAL FROM STUDY AND REFUSAL TO PARTICIPATE

Taking part in this clinical research study is voluntary and you can refuse to take part or stop at any time without stating a reason. Your withdrawal will not affect anything to which you would otherwise be entitled.

Special care will need to be taken when determining if you need to stop the study, with your health as the first priority. Your participation in this study may be stopped at any time by a) the researcher, b) the Institutional Review Board (a review group that gives approval to your study doctor to conduct this study), and (c) other appropriate regulatory agencies.

COST OF TREATMENT

All professional and diagnostic fees for tests and procedures that are part of this study will be provided free to you.

COMPENSATION FOR PARTICIPATION

There will be no compensation for participation in the study.

MEDICAL TREATMENT AND COMPENSATION FOR STUDY-RELATED INJURY

I understand that if I am injured in the course of this study, I alone may be responsible for the costs of treating my injuries. If I am injured (hurt) as a result of being in this study, the Kinesiology and Rehabilitative Science Department will give me immediate treatment needed for my injuries. I will then be told where I may get other treatment for my injuries if needed. The cost of further treatment will be charged to my insurance company or to me. If my insurance company will not pay for these costs, they will be my responsibility. The Department has no program to compensate me in the form of money or anything else should I have an injury. You should immediately contact your researcher at the contact information shown below if you have any study-related illness or injury.

SOURCE FOR ADDITIONAL INFORMATION

If at any time between your visits you feel that any of your symptoms are causing you problems, or you have experienced a study-related injury, please contact your study doctor. The telephone number to reach your researcher or another authorized person is:

Dr. Ronald Hetzler or Morgan Kocher

1337 Lower Campus Rd PE/A 231, Honolulu, HI 96822

Phone: 808-956-7606

This voluntary consent form and study have been approved by an Independent Institutional Review Board (IRB) or Ethics Committee (EC). The IRB or EC is a group of scientific and non-scientific people who watch over research involving humans by following the guidelines and rules of the U.S. Food and Drug Administration. For any questions about your rights as a research subject, please direct inquiries to:

Human Studies Program
University of Hawaii
e-mail: uhirb@hawaii.edu
Phone: (808) 956-5007

GENERAL STATEMENT ABOUT PRIVACY

Records identifying you will be kept confidential and, to the extent permitted by applicable laws and/or regulations, will not be made publicly available. In the event of any publication regarding this study, your identity will remain confidential.

Representatives from government agencies, including institutional review boards, may need access to your original medical records and study records for the purpose of checking data collected for the study. By signing this consent form, you authorize this access.

Your coded study information and samples may also be used for additional unanticipated medical and/or scientific research projects in the future (but at all times in compliance with applicable law and regulation).

By signing this consent form you agree that you will not be able to have access to information about your participation in the study until the study is over. After that, you can obtain access to your information through your researcher.

AUTHORIZATION TO USE AND DISCLOSE RECORDS

For purposes of this study, the study doctor and the clinic will use medical information ("records") collected or created as part of the study that identifies you by name or in some other way, such as test results, identifiable blood or tissue samples, x-ray images, physical exam reports, medical history, and any other data collected or reviewed during the study. By signing this consent, you will permit the study doctor and the clinic to obtain any of your records that they request for study purposes from your regular doctor and/or your other health care providers. You also have the choice of having some of your laboratory results that are available to the site sent to your private doctor. By signing, you agree that the study doctor and the clinic may use and share this information with the parties described below. You agree that, during the study, you may not see some of your records obtained or created as part of this study. You may be allowed to see this information once the study is finished.

Unless required by law, the study doctor and the clinic will share your records only with the study staff and other professionals involved in the study, and the Institutional Review Board (University of Hawaii Human Studies Program). Although efforts will be made to protect your privacy, absolute confidentiality of your records cannot be guaranteed, which may mean the information could be re-disclosed and not protected by federal privacy law.

You have the right to cancel your permission at any time by giving written notice to the researcher. If you cancel this authorization, then the researcher will no longer use or disclose your records, unless it is necessary to do so to preserve the scientific integrity of the study. Canceling this authorization will not affect previous or future uses of the information that had been previously collected.

If you do not give your permission by signing this consent, or if you cancel this authorization later, you will not be able to participate in this study. Unless and until you do withdraw your permission, it will remain valid and effective.

AGREEMENT TO BE IN THE STUDY

By signing this informed consent form, I acknowledge that:

- (1) I have carefully read and understand the information presented in this consent document.
- (2) The purpose and procedures related to this research study have been fully explained to me and I have had the opportunity to ask questions and all of my questions were answered to my satisfaction.
- (3) I have been informed of the parts of the program that are experimental and of the possible discomforts, symptoms, adverse events and risks that I might reasonably expect, and the possible complications, if any, that I might reasonably experience from both known and unknown causes as a result of my participation.
- (4) I understand that I am free to withdraw this authorization and to discontinue my participation in this program any time. The consequences and risks, if any, of withdrawing from the program while it is ongoing have been explained to me.
- (5) I understand that such withdrawal will not affect my ability to receive medical care to which I might otherwise be entitled.

Subject (or legally authorized representative)

_____ Subject Printed Name (or legally authorized representative)	_____ Signature	_____ Date
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Description of Legal Representative's Authority (e.g., parent or legal guardian)

Person Obtaining Consent

_____ Printed Name & Title	_____ Signature	_____ Date
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Appendix B: ACSM Absolute and Relative Contraindications to Resistance Training and Testing

Absolute

- Unstable coronary heart disease
- Decompensated heart failure
- Severe pulmonary hypertension (mean pulmonary arterial pressure >55 mmHg)
- Severe and symptomatic aortic stenosis
- Acute myocarditis, endocarditis, or pericarditis
- Uncontrolled hypertension (>180/110 mmHg)
- Aortic dissection
- Marfan syndrome
- High intensity resistance training (80% to 100% of 1RM) in patients with active proliferative retinopathy or moderate or worse non-proliferative diabetic retinopathy

Relative

- Major risk factors for coronary heart disease
- Diabetes at any age
- Uncontrolled hypertension (>160/100 mmHg)
- Low functional capacity (<4 METs)
- Musculoskeletal limitations
- Individuals who have implanted pacemakers or defibrillators

Appendix C: Medical History Questionnaire

Name: _____ Date of Birth: _____ SID: _____

Date of Birth: _____ Age (years): _____ Ethnicity: _____

In Case of Emergency, whom may we contact?

Name: _____ Relationship: _____

Phone: _____

Do you participate in regular physical exercise? ☐ YES ☐ NO If yes, briefly describe:

Have you previously participated in resistance training? ☐ YES ☐ NO

If yes, briefly describe: _____

Have you participated in regular resistance training in the past three months (at least 1 hr three times per week)? ☐ YES ☐ NO

Are you on any medication? ☐ YES ☐ NO If yes, briefly list the medication and the condition it is intended to treat:

Appendix D: AHA/ACSM Health/Fitness Facility Pre-Participation Screening Questionnaire

Assess your health status by marking all *true* statements

History

- ☐ a heart attack
- ☐ heart surgery
- ☐ cardiac catheterization
- ☐ coronary angioplasty (PTCA)
- ☐ pacemaker/implantable cardiac defibrillator/rhythm disturbance
- ☐ heart valve disease
- ☐ heart failure
- ☐ heart transplantation
- ☐ congenital heart disease

Symptoms

- ☐ You experience chest discomfort with exertion
- ☐ You experience unreasonable breathlessness
- ☐ You experience dizziness, fainting, or blackouts
- ☐ You experience ankle swelling
- ☐ You experience unpleasant awareness of a forceful or rapid heart rate
- ☐ You take heart medications

Other health issues

- ☐ You have diabetes
 - ☐ You have asthma or other lung disease
 - ☐ You have burning or cramping sensation in your lower legs when walking short distance
 - ☐ You have musculoskeletal problems that limit your physical activity
 - ☐ You have concerns about the safety of exercise
 - ☐ You take prescription medication
 - ☐ You are pregnant
-

Cardiovascular risk factors

- ☐ You are a man ≥ 45 yr
 - ☐ You are a woman ≥ 55 yr
 - ☐ You smoke or quit smoking within the previous 6 months
 - ☐ Your blood pressure is $\geq 140/90$ mmHg
 - ☐ You do not know your blood pressure
 - ☐ You take blood pressure medication
 - ☐ Your blood cholesterol level is ≥ 200 mg·dL⁻¹
 - ☐ You do not know your cholesterol level
 - ☐ You have a close blood relative who had a heart attack or heart surgery before age 55 (father or brother) or age 65 (mother or sister)
 - ☐ You are physically inactive (*i.e.*, you get <30 min of physical activity on at least 3 d per week)
 - ☐ You have a body mass index ≥ 30 kg·m⁻²
 - ☐ You have prediabetes
 - ☐ You do not know if you have prediabetes
 - ☐ None of the above
-

If you marked any of these statements in this section, consult your physician or other appropriate health care provider before engaging in exercise. You may need to use a facility with a **medically qualified staff**.

If you marked two or more of the statements in this section you should consult your physician or other appropriate health care provider as part of good medical care and progress gradually with your exercise program. You might benefit from using a facility with a **professionally qualified exercise staff** to guide your exercise program.

You should be able to exercise safely without consulting your physician or other appropriate health care provider in a self-guide program or almost any facility that meets your exercise program needs.

Appendix E: George Non-Exercise Test

Perceived Functional Ability (PFA)

Suppose you were going to exercise continuously on an indoor track for 1 mile. Which exercise pace is just right for you –not too easy and not too hard?

- 1 Walking at a slow pace (18 minutes per mile or more)
- 2 Walking at a slow pace (17-18 minutes per mile)
- 3 Walking at a medium pace (16-17 minutes per mile)
- 4 Walking at a medium pace (15-16 minutes per mile)
- 5 Walking at a fast pace (14-15 minutes per mile)
- 6 Walking at a fast pace (13-14 minutes per mile)
- 7 Jogging at a slow pace (12-13 minutes per mile)
- 8 Jogging at a slow pace (11-12 minutes per mile)
- 9 Jogging at a medium pace (10-11 minutes per mile)
- 10 Jogging at a medium pace (9-10 minutes per mile)
- 11 Jogging at a fast pace (8-9 minutes per mile)
- 12 Jogging at a fast pace (7-8 minutes per mile)
- 13 Running at a fast pace (7 minutes per mile or less)

How fast could you cover a distance of 3 miles and NOT become breathless or overly fatigued?

Be realistic

- 1 I could walk the entire distance at a slow pace (18 minutes per mile or more)
- 2 I could walk the entire distance at a slow pace (17-18 minutes per mile)
- 3 I could walk the entire distance at a medium pace (16-17 minutes per mile)
- 4 I could walk the entire distance at a medium pace (15-16 minutes per mile)
- 5 I could walk the entire distance at a fast pace (14-15 minutes per mile)
- 6 I could walk the entire distance at a fast pace (13-14 minutes per mile)
- 7 I could jog the entire distance at a slow pace (12-13 minutes per mile)
- 8 I could jog the entire distance at a slow pace (11-12 minutes per mile)
- 9 I could jog the entire distance at a medium pace (10-11 minutes per mile)
- 10 I could jog the entire distance at a medium pace (9-10 minutes per mile)
- 11 I could jog the entire distance at a fast pace (8-9 minutes per mile)
- 12 I could jog the entire distance at a fast pace (7-8 minutes per mile)
- 13 I could run the entire distance at a fast pace (7 minutes per mile or less)

Physical Activity Rating (PA-R)

Select the number that best describes your overall levels of physical activity for the previous 6 MONTHS:

- 0 avoid walking or exertion; e.g., always use elevator, drive when possible instead of walking
- 1 **Light activity:** walk for pleasure, routinely use stairs, occasionally exercise sufficiently to cause heavy breathing or perspiration
- 2 **Moderate activity:** 10 to 60 minutes per week of moderate activity; such as golf, horseback riding, calisthenics, table tennis, bowling, weight lifting, yard work, cleaning house, walking for exercise
- 3 **Moderate activity:** over 1 hour per week of moderate activity as described above
- 4 **Vigorous activity:** run less than 1 mile per week or spend less than 30 minutes per week in comparable activity such as running or jogging, lap swimming, cycling, rowing, aerobics, skipping rope, running in place, or engaging in vigorous aerobic-type activity such as soccer, basketball, tennis, racquetball, or handball.
- 5 **Vigorous activity:** run 1 mile to less than 5 miles per week, or spend 30 minutes to less than 60 minutes per week in comparable physical activity as described in 4 above.
- 6 **Vigorous activity:** run 5 miles to less than 10 miles per week or spend 1 hour to less than 3 hours per week in comparable physical activity as described in 4 above
- 7 **Vigorous activity:** run 10 miles to less than 15 miles per week or spend 3 hours to less than 6 hours per week in comparable physical activity as described in 4 above
- 8 **Vigorous activity:** run 15 miles to less than 20 miles per week or spend 6 hours to less than 7 hours per week in comparable physical activity as described in 4 above
- 9 **Vigorous activity:** run 20-25 miles per week or spend 7 to 8 hours per week in comparable physical activity as described in 4 above
- 10 **Vigorous activity:** run over 25 miles per week or spend over 8 hours per week in comparable physical activity as described in 4 above

Appendix F: National Strength and Conditioning Association

Estimated 1RM Table

Max Reps (RM)	1	2	3	4	5	6	7	8	9	10	12	15
%1RM	100	95	93	90	87	85	83	80	77	75	67	65
	10	10	9	9	9	9	8	8	8	8	7	7
	20	19	19	18	17	17	17	16	15	15	13	13
	30	29	28	27	26	26	25	24	23	23	20	20
	40	38	37	36	35	34	33	32	31	30	27	26
	50	48	47	45	44	43	42	40	39	38	34	33
	60	57	56	54	52	51	50	48	46	45	40	39
	70	67	65	63	61	60	58	56	54	53	47	46
	80	76	74	72	70	68	66	64	62	60	54	52
	90	86	84	81	78	77	75	72	69	68	60	59
	100	95	93	90	87	85	83	80	77	75	67	65
	110	105	102	99	96	94	91	88	85	83	74	72
	120	114	112	108	104	102	100	96	92	90	80	78
	130	124	121	117	113	111	108	104	100	98	87	85
	140	133	130	126	122	119	116	112	108	105	94	91
	150	143	140	135	131	128	125	120	116	113	101	98
	160	152	149	144	139	136	133	128	123	120	107	104
	170	162	158	153	148	145	141	136	131	128	114	111
	180	171	167	162	157	153	149	144	139	135	121	117
	190	181	177	171	165	162	158	152	146	143	127	124
	200	190	186	180	174	170	166	160	154	150	134	130
	210	200	195	189	183	179	174	168	162	158	141	137
	220	209	205	198	191	187	183	176	169	165	147	143
	230	219	214	207	200	196	191	184	177	173	154	150
	240	228	223	216	209	204	199	192	185	180	161	156
	250	238	233	225	218	213	208	200	193	188	168	163
	260	247	242	234	226	221	216	208	200	195	174	169
	270	257	251	243	235	230	224	216	208	203	181	176
	280	266	260	252	244	238	232	224	216	210	188	182
	290	276	270	261	252	247	241	232	223	218	194	189
	300	285	279	270	261	255	249	240	231	225	201	195
	310	295	288	279	270	264	257	248	239	233	208	202
	320	304	298	288	278	272	266	256	246	240	214	208
	330	314	307	297	287	281	274	264	254	248	221	215
	340	323	316	306	296	289	282	272	262	255	228	221
	350	333	326	315	305	298	291	280	270	263	235	228
	360	342	335	324	313	306	299	288	277	270	241	234
	370	352	344	333	322	315	307	296	285	278	248	241
	380	361	353	342	331	323	315	304	293	285	255	247
	390	371	363	351	339	332	324	312	300	293	261	254
Max Reps (RM)	1	2	3	4	5	6	7	8	9	10	12	15
%1RM	100	95	93	90	87	85	83	80	77	75	67	65

	400	380	372	360	348	340	332	320	308	300	268	260
	410	390	381	369	357	349	340	328	316	308	275	267
	420	399	391	378	365	357	349	336	323	315	281	273
	430	409	400	387	374	366	357	344	331	323	288	280
	440	418	409	396	383	374	365	352	339	330	295	286
	450	428	419	405	392	383	374	360	347	338	302	293
	460	437	428	414	400	391	382	368	354	345	308	299
	470	447	437	423	409	400	390	376	362	353	315	306
	480	456	446	432	418	408	398	384	370	360	322	312
	490	466	456	441	426	417	407	392	377	368	328	319
	500	475	465	450	435	425	415	400	385	375	335	325
	510	485	474	459	444	434	423	408	393	383	342	332
	520	494	484	468	452	442	432	416	400	390	348	338
	530	504	493	477	461	451	440	424	408	398	355	345
	540	513	502	486	470	459	448	432	416	405	362	351
	550	523	512	495	479	468	457	440	424	413	369	358
	560	532	521	504	487	476	465	448	431	420	375	364
	570	542	530	513	496	485	473	456	439	428	382	371
	580	551	539	522	505	493	481	464	447	435	389	377
	590	561	549	531	513	502	490	472	454	443	395	384
	600	570	558	540	522	510	498	480	462	450	402	390

Appendix G: Borg's Ratings of Perceived Exertion (RPE)

Rating	Perceived Exertion
6	No Exertion
7	Extremely Light
8	
9	Very Light
10	
11	Light
12	
13	Somewhat Hard
14	
15	Hard
16	
17	Very Hard
18	
19	Extremely Hard
20	Maximal Exertion